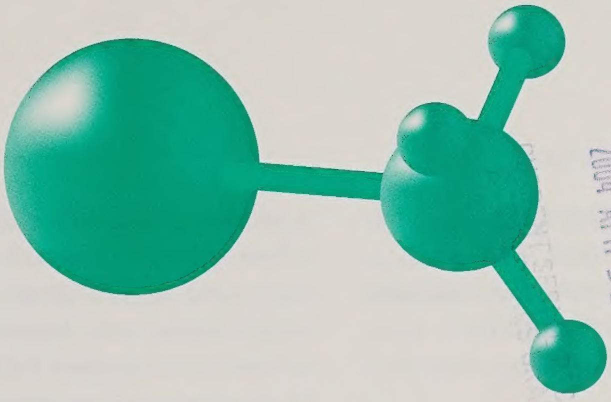
Methyl Bromide *Alternatives*



USDA
Vol. 9, No. 2
Fall 2003

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This issue and all back issues of the *Methyl Bromide Alternatives* newsletter are now available at **http://www.ars.usda.gov/is/np/mba/mebrhp.htm**. For additional information, visit the ARS methyl bromide research homepage at **http://www.ars.usda.gov/ismbmebrweb.htm**.

This newsletter provides information on research for methyl bromide alternatives from USDA, universities, and industry.

Address technical questions to Nancy Ragsdale, USDA, ARS, National Program Staff, 5601 Sunnyside Ave., Beltsville, MD 20705-5139. Phone (301) 504-4509, fax (301) 504-5987.

Address suggestions and requests to be added to the mailing list to Sharon Durham, USDA, ARS, Information Staff, 5601 Sunnyside Ave., Beltsville, MD 20705-5129. Phone (301) 504-1611, fax (301) 504-1641.

Introduction to Reports From the U.S./Canada Working Group on Methyl Bromide Alternatives

This issue contains presentations made at the U.S./Canada Working Group on Methyl Bromide Alternatives Meeting, May 28–29, 2003, Indianapolis, Indiana. After the phase-out of methyl bromide was initiated in 1992, a number of small meetings were convened among U.S. and Canadian government and industry individuals to discuss the challenges of common interest resulting from the phase-out. At the International Research Conference on Methyl Bromide Alternatives in Orlando, Florida, in November 1996, a working group was formed consisting of Canadian and U.S. experts. This group agreed to focus on two main objectives:

- To enhance collaboration and avoid duplication, in terms of research, development, and technology transfer, between the two nations; and
- To accelerate the development and technological transfer of alternatives to methyl bromide within the two nations.

These objectives are effected through the following mechanisms:

- Identification of priority research needs;
- Identification of gaps where research might be required;
- Development and implementation of joint projects of benefit to both nations, with an emphasis on production-based trials and demonstrations;
- Identification and sharing of results of research and development projects within each nation; and
- Facilitation of the registration process for alternative products and technologies.

The working group currently is co-chaired by Judy St. John, U.S. Department of Agriculture (USDA), Agricultural Research Service, and Dale McKeague, Environment Team, Agriculture and Agri-food Canada. Meetings take place two times per year, once in November in conjunction with the International Conference and once in the summer, alternating between U.S. and Canadian locations. The co-chairs decide on a subject of common interest for the summer meeting; the subject can be a factor in the selection of a meeting site. Subjects of interest to both countries have been primarily focused on milling, grain fumigation, and nursery production of strawberry plants.

Advances in Organic Hermetic Storage and Vacuum-Hermetic Fumigation (V-HF) or Gas-Hermetic Fumigation (G-HF)

Philippe Villers
President
GrainPro, Inc.
200 Baker Avenue, Suite 309
Concord, MA 01742
e-mail: *pvillers@igc.org*

Introduction

In response to the international agreement to phase out the use of methyl bromide, many alternatives for protecting stored commodities have been proposed in recent years, but none are as simple and as environmentally benign as hermetic storage. Modern hermetic storage uses large, flexible, polyvinyl chloride (PVC) envelopes called cocoons to create a low-oxygen environment in which insects quickly die for lack of oxygen. Attendant benefits of this flexible low-oxygen environment include the maintenance of constant moisture levels, the prevention of fungal growth and its associated aflatoxins, and the prevention of rodent access. Hermetic systems make safe, long-term storage feasible without the use of pesticides and are now in use in some 20 countries. In addition, hermetic storage is now widely used to preserve seed germination potential for many months even in hot, humid environments without requiring refrigeration.

The storage takes three forms, depending on the mechanism used to reduce oxygen levels to about 2 percent. Organic hermetic storage relies on the respiration of the infesting insects themselves to reduce the oxygen level to this unsurvivable level. Vacuum-hermetic fumigation (V-HF) uses an attached vacuum pump. Gas-hermetic fumigation (G-HF) introduces carbon dioxide to drive out air and replaces it with carbon dioxide, maintaining a normal atmospheric pressure. Each of these three processes has its natural niche, depending on whether the interest is in use as long-term storage or rapid fumigation, and whether the commodity is resistant to vacuum or is fragile and might be crushed, as in the case of figs and dates. In all cases, these gas-tight envelopes (cocoons) are made from approximately 1/32-inch-thick PVC, which has low gas permeability and high resistance to UV radiation.

Scientific Basis of Hermetic Storage and Current Usage

When cocoons are used for organic hermetic storage, insect respiration typically causes the oxygen level to reach below 2 percent within a few days and the carbon dioxide level to climb. At this point, adult insect life cannot be sustained. Over time oxygen infiltrates and eggs, which are more resistant to low oxygen levels, may hatch and a second cycle of reduced intensity can take place. However, in all cases, the cumulative losses at room temperature and above are generally below 1 percent before all insect activity ceases. Safe, long-term storage of paddy and milled rice, which is even more demanding, is possible with no quality deterioration over extended periods of time, up to 6 months or more. Wheat has been stored with no significant degradation for 5 years in cocoons. In Central America, cocoons are now used to retain flavor in coffee beans over multimonth storage.

GrainPro, Inc., research shows that fungal population is a very strong function of relative humidity. Hermetic storage, by preserving constant relative humidity, prevents the growth of fungi and therefore aflatoxins. In addition, fungi do not thrive in low-oxygen, high–carbon dioxide atmospheres.

Recent Results

V-HF field tests in the last several years have shown that, with high-value commodities such as coffee, cocoa, and Narcissus bulbs, the use of vacuum allows quick, complete fumigation by using a commonly available vacuum pump. Under this patented process, adult insects die even more rapidly, but even the most resistant life forms, such as eggs, typically are killed in less than 3 days at room temperature. Faster kill times are observed at higher temperatures. In the summer and fall of 2003, additional field tests were performed on apples, matzo flour, corn chips, cocoa, semolina, wheat flour, Narcissus bulbs, rice, almonds, chick peas, sunflower seeds, and peanuts.

Where the commodity is fragile and crushable, such as figs, dates, and cut flowers, G-HF is used, where the vacuum pump is replaced by a carbon dioxide source. This is now being used on a significant basis in Turkey with

figs. Recently a high-throughput fumigation facility using a special type of cocoon has been developed, called the PIT system (Pesticide-Free Integrated Transportation and Storage). This system allows for rapid in and out processing. In this system, the use of an insect-resistant membrane, called PalletWrap, protects a skidload once it has been "fumigated" with V-HF or G-HF. This approach makes the skid-mounted commodities easy to handle in all stages of shipment—from fumigation to transportation in 20-foot containers to storage at the country of destination—and all without danger of reinfestation.

Practical Aspects

PVC cocoons are lightweight and easy to transport. For instance, a 10-metric-ton capacity cocoon weighs only 49 kg. Cocoons are available in sizes that range from a capacity of 5 to 300 metric tons. GrainSafes, which allow dispensing of bulk grains at will, are designed for small users and have capacities of 0.5 to 1.0 metric tons. Both of these storage types are easy to maintain and repair. Cocoons are sealed with a zipper originally designed for space suits and any tear that may accidentally be introduced can easily be repaired with a patch kit, much as is done with a bicycle inner tube. When cocoon sides are made taut, which is done with tensioning straps, rodents cannot get a toothhold on its tough, slippery surface. Cocoons are currently used to store a large variety of commodities ranging from rice and corn seed to paddy, wheat, corn, beans, sorghum, dates, figs, and nuts.

Conclusion

Use of hermetic storage (cocoons) avoids the need for pesticides in medium- and long-term storage. Storage can take place either indoors or outdoors, in warehouses or on unprepared ground. Cocoons effectively control storage insects and fungi, either alone or with the addition of vacuum or carbon dioxide for rapid fumigation. Rapid fumigation, in 3 days at room temperature with V-HF or G-HF, has now been proven effective for a number of commodities, and experiments are ongoing.

Much of the recent experimental work was done under a grant from the US-Israel Science and Technology Foundation under the project title "Development of Alternative Fumigation Systems and Methods to Reduce Methyl Bromide Emissions in Post-Harvest Treatment."

ProFume Gas Fumigant—An Overview

Christopher Voglewede
Technology Transfer Leader
Brian Schneider
Biology Research and Development
Dow AgroSciences
9330 Zionsville Road
Indianapolis, IN 46033

Dow AgroSciences has been developing ProFume* gas fumigant (99.8% sulfuryl fluoride) for over 7 years to control stored-product pests in milling, food processing, and food storage facilities. The large research and development program has been undertaken in cooperation with academic, industry, and government researchers, as well as with fumigators and millers.

Sulfuryl fluoride (SF) possesses many positive fumigant qualities, including efficacy in controlling a broad spectrum of insect pests, a low boiling point, excellent penetration qualities, low reactivity potential, limited sorption, and rapid aeration. SF is inorganic, not combustible, has no flash point, and is very stable under most fumigation environments. Over 30 wheat flour, rice mill, pet food processing, and dried fruit and tree nut chamber fumigations have been conducted with no effects on computer, electrical, or mechanical systems. Also, Vikane* gas fumigant (sulfuryl fluoride), another formulation of sulfuryl fluoride, has been successfully used for over 40 years in structures containing sensitive electronic equipment and a wide variety of materials and contents.

Research in both the laboratory and field confirms that SF is effective on all life stages of postharvest insect pests. Tested species include Indian meal moth, red and confused flour beetles, warehouse beetle, Mediterranean flour moth, sawtoothed grain beetle, codling moth, navel orangeworm, Turkish grain beetle, yellow mealworm, lesser grain borer, granary weevil, and rice weevil. Larvae, pupae, and adult insects are highly susceptible to SF while eggs are more tolerant. However, effective dosages for all life stages can be obtained by varying concentration and expo-

sure time. Lower dosages can be used at higher temperatures because of increased insect metabolism.

Results from over 30 research fumigations in actual mills have been conducted in the United States, Germany, Italy, France, Switzerland, and the United Kingdom. These ProFume fumigations have provided insect control that is equivalent to or better than current methyl bromide programs. These trials have also indicated no damage to sensitive equipment or electronic controls and no increase in total fumigation time or mill down time when compared with present methyl bromide fumigations.

The mode of action of SF is disruption of the glycolysis and fatty acid cycles, thus preventing insects from metabolizing the stored fats they need to maintain a sufficient source of energy for survival. Modeling studies conducted on Indian meal moth and red flour beetle indicated that there is a very low probability for resistance development. Preliminary results testing SF on a strain of phosphine-resistant red flour beetle indicated no cross-resistance. ProFume can also be used as part of an active, planned management program as a rotational treatment to prevent or delay development of insecticide resistance or as a tool to control phosphine-resistant insect populations.

Food residue studies have been conducted on a variety of commodities. With some limitations, tolerances and maximum residue limits for both SF and fluoride (the two terminal food residues of interest) will be established to support the fumigation of a wide variety of grains, dried fruits, tree nuts, and processed foods. Country approval in Switzerland has already occurred for empty mills. Registrations are anticipated in the United States in 2003 and in the European Union in 2004.

Extensive taste and quality trial results indicate that dried fruit and tree nuts are not negatively affected by ProFume. Wheat kernel quality trials showed that ProFume exposure did not affect the nutritional characteristics or the rheological properties of the milled fractions of hard red winter, soft red winter, and durum wheat kernels.

Fumigation with ProFume will require the use of the Fumiguide* Program for ProFume gas fumigant (ProFume Fumiguide). The ProFume Fumiguide, a PC-based software program, will be an excellent educational and operational tool, allowing the fumigator to consider multiple fumigation scenarios prior to deciding on the optimal fumigation plan. Also, by helping the fumigator apply only the fumigant necessary to control the target pests, use of the ProFume Fumiguide will refine precision fumigation techniques, increase the use of precision fumigation practices, and help achieve a very high stewardship standard. Precision fumigation is defined as optimizing fumigant use to maximize efficiency and minimize risk.

Dow AgroSciences has a long history of responsible stewardship with gas fumigants, particularly with SF for the structural fumigation market. As with Vikane, Dow AgroSciences will deliver comprehensive ProFume training and implement a stewardship program emphasizing worker, bystander, and environmental safety. The stewardship program will consist of classroom training, an examination to demonstrate competency in key areas of label and precision fumigation practices, simulated on-the-job critical fumigation scenarios, and Dow AgroSciences–assisted fumigations. Additionally, an annual training update, label review, and quality assurance review will be conducted. Only licensed fumigators who have completed this training will be allowed to purchase and use ProFume.

**Trademark of Dow AgroSciences LLC. ProFume is not yet registered and is not for sale in the United States.*

Introducing Methyl Bromide Scrubbing Technology: Instantaneous Capture and Destroy for Quarantine/Preshipment, Critical, and Emergency Use

Peter J. Joyce
President
Value Recovery, Inc.
510 Heron Drive, Suite 301
Bridgeport, NJ 08014
e-mail: *joyce@ptcvalue.com*

Methyl bromide's reactivity has not been thoroughly explored as a capture-and-destroy removal strategy to protect the ozone layer.

This critical attribute—reactivity—is both methyl bromide's most beneficial attribute with respect to fumigation efficacy and its Achilles' heel with respect to environmental impact. When used as a fumigant, methyl bromide can interrupt an organism's internal chemical reactions, thus shutting down the organism. In the upper atmosphere, methyl bromide reacts at low temperatures with ozone, thus destroying the ozone layer's ability to provide protective filtering of UV light from the sun. Harnessing methyl bromide's reactivity in the form of a scrubbing solution that has been designed to provide exceptionally high reaction rates is the key to a new capture-and-destroy strategy that may supply the missing link in the methyl bromide phase-out program.

Value Recovery, Inc., of Bridgeport, New Jersey, believes that exploiting methyl bromide's strong suit, its reactivity, can result in an effective, safe, and cheap way to keep methyl bromide from ever reaching the upper atmosphere. The process takes place in a "reactive scrubber." Methyl bromide–laden air is forced through the reactive scrubbing solution and the air emerges essentially free of methyl bromide. A water-soluble organic compound or anion in the scrubbing liquor reacts with the methyl bromide to form a benign organic product and sodium bromide.

The technology used is based on phase transfer catalysis or PTC, whose salient feature is that it brings reactants from different phases together to react when they normally would not have a chance of reacting. PTC has been around for over 30 years and is the subject of over 2,000 patents and 10,000 peer-reviewed journal articles. Elite academics and specialty chemical companies use PTC to make high-molecular-weight pharmaceutical chemicals and other similar sophisticated molecules. PTC participates in at least one manufacturing step in over \$10 billion worth of specialty chemical sales. Currently, Value Recovery is the only company dedicated to applying PTC to the environmental field. The company has identified over 180 million kg per year of production-related waste documented in the U.S. Toxic Release Inventory that could be transformed into salable products using PTC technology. Funding for this work was initiated under the U.S. Department of Energy Office of Industrial Technology.

A small-scale field demonstration of the technology was done on February 28, 2003, in conjunction with Rudi Scheffrahn of the University of Florida, who is advocating using methyl bromide to destroy anthrax spores. During fumigation of a University of Florida office trailer containing surrogate anthrax spores, a slipstream containing over 20,000 ppm (>80 oz/1000 ft^3) of methyl bromide was charged to small gas washing bottles containing the reactive scrubber solution. The outlet concentration averaged 4 ppm and a steady-state value of 2 ppm was achieved in a 4-hour test demonstrating over 99.9 percent removal in less than 1 second of contact time. The air feed rate in the gas washing bottles was very low so these experiments do not represent a conclusive test in terms of commercial viability. However, the results do show that the reaction rate is exceptionally fast and that the reaction rate does not control the overall removal rate of methyl bromide from air. Thus, the approach is similar to scrubbing acid gases such as hydrochloric acid with sodium hydroxide to make sodium chloride (table salt) and water. This process also uses a reactive scrubber principle where the acid-base reaction is very fast. Results from the Florida test are available at http://www.ptcvalue.com/app3.asp.

The scrubber liquor used in the Florida tests is not suitable for introduction into the environment because the waste produced from it would be hazardous. Thus, this particular formula would be used only for demonstration. However, subsequent research results (as yet unpublished) from the company show that a formula based on a nonhazardous scrubbing liquor is feasible and that the company is actively working in this direction. The components of the scrubbing liquor are both cheap and relatively easy to acquire. The next steps are to scale the process up to conventional scrubber contacting equipment and to validate the technology through the appropriate environmental authorities.

In summary, a new technology has emerged that can potentially provide an economic and environmentally benign way to capture and destroy methyl bromide that continues to be used under the exemptions from phase-out for emergency use, critical use, and

quarantine/preshipment (QPS). QPS applications such as fumigation of perishable commodities are particularly well suited to this technology because of the limited time available to accomplish dockside fumigations. The method is based on applying reactive scrubber technology to totally remove highly reactive methyl bromide and convert it to environmentally benign products. The gas–liquid contact times are on the order of seconds. Patent applications have been submitted.

Residual Products

Frank Arthur
Entomologist
USDA Agricultural Research Service
1515 College Avenue
Manhattan, KS 66502
e-mail: *arthur@gmprc.ksu.edu*

Historically methyl bromide was not extensively used as a grain fumigant in the United States and, until the early to mid-1980s, there were several registered fumigants that could be used instead of methyl bromide. Today phosphine is the only other fumigant still labeled for raw stored grains, and it receives heavy use by the grain industry. Methyl bromide is more commonly used in mills, processing plants, and food warehouses. The Methyl Bromide Technical Options Committee (MBTOC) has on several occasions listed a variety of control strategies that are considered as alternatives to methyl bromide for indoor and structural treatment. These alternatives are not limited to other fumigants: they include residual surface sprays, aerosol and fogging applications, sanitation and cleaning, targeted control for specific areas, and sampling and monitoring of insect populations to determine the need for insecticide application.

Several residual sprays are labeled for direct application to floors and walls of mills, warehouses, food processing plants, and other indoor areas. One example of a residual spray is cyfluthrin (Tempo), a pyrethroid insecticide labeled as both a general surface spray and a crack-and-crevice spray. Another example is the insect growth regulator hydroprene, which is labeled as an aerosol and as a residual surface spray. Some organophosphates are still registered for use in mills and processing plants, but only as crack-and-crevice or spot applications or applications to outside perimeters around structures. Other pyrethroids are also labeled as surface or crack-and-crevice sprays, and the insecticide label will always give the specifications for use along with the application rates for specific areas or locations.

Current research with residual products encompasses several broad areas, including evaluation of new products for control of stored-product insects, improving the performance of existing products, and identifying the factors that can affect insecticide efficacy. The temperature at which insects are exposed to a particular insecticide often affects residual performance and actual persistence of the chemical. The presence of food material, either during or after the insects' exposure to residual chemicals, often leads to higher survival rates. Sanitation and cleaning in conjunction with pesticide applications is extremely important because trash and spilled material can compromise pesticide efficacy. Insect species vary in their response to particular insecticides: some species are simply more susceptible than others to a particular insecticide. Also, susceptibility can be different depending on the specific insecticide or class of insecticides used. Finally, the actual time that insects are directly exposed to a residual insecticide often affects mortality, and some insecticides kill at faster rates than others.

Movement of insects over and through a treated surface can be important, especially if they are repelled by the insecticide, or if they can avoid exposure or even move through the treated area without being affected by the insecticide. Insects exploit individual food patches or selected areas and may never come into contact with the insecticide. Population dispersal from centers of infestation and how insects disperse from these centers can also affect control efforts, particularly when the centers of infestation are not located in the same areas that are being treated with insecticides.

One of the goals in pest management programs is to identify the source of infestation and target control efforts toward that source or area of infestation. Certain areas within a facility may be more vulnerable to infestation, and efforts can be targeted to those sites. However, insects can still move from untreated areas, and

populations may quickly rebound even after insecticide treatment. Researchers are employing several strategies for identifying and mapping the distribution of insect populations. Spatial mapping can be used to chart the dispersal and movement of insect populations, and it often can point out that the source of an infestation may be well away from any areas being treated with residual insecticides.

Another area of emphasis is identification and selection of new reduced-risk, low-toxicity chemicals to replace older neurotoxins. Some insecticides that are now being used for cockroach control in urban pest management may be products that potentially can be used as residual sprays for stored-product insects. Insect growth regulators and other products that are specific to insects are examples of insecticides that are being tested and evaluated for stored-product insects.

Residual insecticides can still be a viable part of modern pest management programs for flour mills, processing plants, and food warehouses. Selected use of residuals may lead to less total insecticide use and could even eliminate some fumigations with methyl bromide. As pest management shifts from a chemical approach to a more knowledge-based strategy for insect pest management, selected use and management of insecticides will be included as a component of broader, more integrated approaches to insect control.

Heat Treatment of Structures and Spaces—A View From the Steam Side

James R. Smith
Certified Energy Manager
Senior Applications Specialist
Armstrong Heat Transfer Group
9008 Canal Place, N.W.
Massillon, OH 44647-0040
e-mail: *jrsmith@armintl.com*

The Armstrong Heat Transfer Group of Armstrong International Inc. has been a leading heat transfer systems supplier to the food industry and other major industries for over 50 years. Armstrong International Inc. is also a global supplier of steam, air, and hot water systems solutions for major industrial, commercial, institutional, and governmental facilities. Armstrong's Heat Transfer Group has supported insect-related heat treatment of food industry facilities for over 30 years. However, there has been a noticeable increase in the demand for this type of pest management in recent years.

Using the available utilities infrastructure found in many food facilities, which often includes steam as a major installed utility, Armstrong's Heat Transfer Group has developed both fixed and portable solutions for heat treatment as part of an integrated pest management program. Directing steam-heated air as a clean, reliable, efficient thermal source results in proven kill rates of targeted insect populations in food facilities.

Major companies, such as General Mills, Nestle (Ralston) Purina, Quaker (Pepsico), Nabisco, and Kraft, have utilized steam-sourced heating equipment from the Armstrong Heat Transfer Group for successful pest elimination programs.

Armstrong coordinates activities as requested by clients with major pest management firms to ensure that a coordinated program for pest control is accomplished.

Armstrong's involvement with the Department of Grain Science and Industry at Kansas State University, Manhattan, Kansas, extends over 10 years of support, equipment supply, and workshop participation. Refer also to recent technical articles produced by Armstrong such as "Equipment Consideration for Steam Heat Treatment as Part of Integrated Pest Management," which discusses technical issues related to selection of steam heating equipment for use in heat treatment.

Because different steam heat treatment applications have some common characteristics but many site-specific variables, it is often not possible or practical to use only standard-sized equipment. However, Armstrong has 22 standardized unit heaters ranging from 10 to 48 in, delivering approximately 800 to 22,000 CFM of air at various output temperatures based on the supplied steam source. Any unit heater can be modified for portable service or be used in multiples depending on the requirement of the applications.

Construction of the Armstrong Unit/Space Heating equipment is

designed around industry-requested heavy-duty construction. This incorporates heavy wall tubes, thick and cleanable fin surfaces, special fin/tube bonding techniques, and all welded construction for pressure parts. TEFC motors are standard, along with OSHA fan guards, heavy gauge enclosures, and louver materials. The units are cleanable in place with compressed air, or the heating cores can be removed for pressure washing. Explosion proof or special electrical considerations can be furnished as applications require.

Initial evaluation of a facility for heat treatment should incorporate initial goals and scope meetings involving not only quality assurance/sanitation personnel and contracted pest management personnel but also utilities/energy plant management, housekeeping, and financial managers. A key factor to success is a site-wide audit to evaluate the true energy infrastructure so that current energy sources can be fully determined for use and the best alternatives can be considered. This should be an in-depth review (available through Armstrong), which, though a chargeable service, can often be rolled into the cost of lease or ownership of equipment.

Placement of steam heating equipment for pest elimination is a combination of art and science. The thermal heat loss calculations determining the BTUs (energy) needed for the service are determined through accepted industry heat transfer calculation criteria and proprietary sizing software.

Once total heat loss is determined, several factors govern the selection of the number of units required to deliver properly distributed heat. These include area layout, mounting height (for fixed/permanent units), throw or spread of coverage per unit, and special targeted area coverage determined through input from plant quality assurance/sanitation or the integrated pest management firm.

A common problem is the desire to have fewer units with higher output temperatures, and higher total BTUs per unit to reduce numbers of heat treatment units required. Often, steam will be used at a much higher pressure (and temperature) than is required for the application. Although this may appear initially to be more economical, such an approach can severely reduce the coverage and lead to stratification of heat, causing much higher temperatures at ceiling levels than at the floor. This results in gradients that are unacceptable and may result in lower kill rates because of some “cool” spots below target temperatures. (Required temperatures are determined by pest management personnel or quality assurance/ sanitation personnel with specific targeted insect requirements.)

Armstrong uses proprietary software to determine the optimum number and size of steam heaters to provide adequate, but not excessive, discharge temperatures. This results in full heat blanketing in the space to ensure reduction of any stratification issues. It has been determined that heating equipment that seemed not to do the job would actually show coverage improvement if steam pressures were varied. The result of slightly lowering outlet temperatures from steam heaters provides for longer throws and spreads of hot air to the targeted space.

The future of steam-based heat treatment design and equipment is to develop the integration between the basic heat transfer device (finned coil air heater), to blend with integrated temperature sensing, control systems, and drainage in units that are fully portable. These designs allow for plant-wide flexibility and ease of storage when the equipment is not needed and result in greater potential use for spot applications as well as larger plant-wide scenarios.

Technological advancements within Armstrong have improved monitoring, reporting, and controlling functions in the steam marketplace. Current control systems being used in energy plant monitoring over wireless control loops and even web-based systems can be adapted to these applications.

Implementing these technologies in heat treatment projects will further advance the flexibility, accuracy of control, and reduction in labor requirements for these critical applications to the food industry.

Heat Treatment as a Methyl Bromide Alternative

Jim Rosborough
Pepsico Foods Canada, Inc.
Quaker Petersborough Plant
34 Hunter Street West
Petersborough, Ontario
Canada K9J 7B2
e-mail: *jim.rosborough@pcfci.com*

The majority of food processing facilities are perfect homes for many food-infesting insects, providing food, warmth, and shelter. At the same time, insecticides such as methyl bromide are being phased out and new ones are taking a long time in the approval process. As the chemical tool kit shrinks, interest in heat treatment as an insect control method is increasing.

The PepsiCo Foods Canada Inc., Quaker Peterborough Plant has been using heat treatment as part of its integrated pest management program for over 30 years. Though insects subjected to 50° C to 60° C will die within minutes, this facility maintains 50° C minimum for 24 hours to ensure that the majority of surfaces reach this lethal temperature.

Planning plays an important part in the heat treatment schedule. A tentative annual plan is developed for the period from Easter to Thanksgiving (mid-October in Canada). This schedule is fine-tuned as the year progresses based on pheromone trap findings and knowledge of insects and trouble spots. Once the date for treatment has been finalized the following areas are prepared: the areas to be heated, heaters, building, equipment, sprinkler system, and employees.

A number of steps are taken to prepare the area to be heated: equipment and ingredient/work-in-process bins are emptied; garbage/salvage receptacles are emptied and cleaned; heat-susceptible ingredients and packaging material are removed; and circulating fans are placed. Insect test cages are put in areas where it is difficult to heat and, if allowed, a residual spray is applied at doorways between heated and unheated areas.

Heater preparation is one of the key steps in ensuring a successful heat run. The heaters and traps are cleaned, and the fans are started to be sure they are functioning properly. New equipment installations or building modifications are also reviewed to determine how air movement may have been affected. This may require the placement of additional fans or the installation of new heaters or relocation of existing heaters.

Building preparation involves the closure and sealing of all doors, windows, and vents. This sealing does not have to be as airtight as for fumigation, but it should restrict the flow of warm air out of or cold air into the structure. Heating, ventilating, and air-conditioning (HVAC) systems and dust collectors are shut off, and plastic is used to seal off areas not being heated. To avoid thermal shock, the following rules are adhered to: 90° F differential rule between inside and outside temperatures and a 10° F temperature rise per hour. (If in doubt, consult a structural engineer.)

There are some precautions that need to be taken when preparing equipment for heat treatment. Catch pans should be in place over product zones because the oil in gearboxes will expand and the lubricant could be forced out of seals. Conveyor belts need to be loosened to prevent stretching. Electrical equipment, such as computers and controllers, must be powered down or removed. (Contact the manufacturer for advice on this.) Wherever possible, equipment should be opened to allow for maximum heat penetration.

The facility sprinkler system must not be overlooked during preparation for heat treatment. High temperature heads should be used in all heated areas: 286° F within 10 feet of heaters and 212° F for all other areas. Also, be prepared for an activated head: know shut-off valve locations and operations and prepare a salvage plan to limit damage to equipment, ingredients, and packaging material.

The success of any insect control activity is highly dependent on the people involved. This is true for heat treatments as well. To be successful, a multidisciplinary team is required consisting of electricians, plumbers, stationary engineers, cleaning crews, sealing crews, temperature monitoring crews, production planning, purchasing, quality assurance, sanitation, and production. Predefining each group's role in the treatment will reduce the chances of errors and increase the rate of success. A special note should be made concerning the temperature monitoring crews:

safety is paramount for these employees. The crews must physically be able to work in 50° C to 60° C conditions for limited periods of time, crews must be made up of a minimum of two employees, cool areas must be provided for rest periods, fluids must be available to prevent dehydration, and these employees must be trained to recognize signs of heat stress.

Once the heat treatment is completed, the following steps should be performed prior to plant start-up: ensure window and door screens are in place for cool down, remove sealing material, close equipment, tighten conveyors, and look for lubricant leakage and top up gearboxes as needed. Personnel responsible for the facility's pest control program should also monitor and record insect fallout, collect and analyze test cages, and review the temperature records from the heat run. This will provide valuable information on insect hot spots within the plant, which could lead to changes in cleaning and inspection practices, as well as point out areas that may require changes to the heater and/or fan placements prior to the next heat treatment.

Regardless of the alternative, we all have the same goal and heat is just another tool in the integrated pest management tool kit.